SEISMIC HAZARD ZONE REPORT 077

SEISMIC HAZARD ZONE REPORT FOR THE WHITAKER PEAK 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

2003

DEPARTMENT OF CONSERVATION
California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Whitaker Peak 7.5-Minute Quadrangle, Los Angeles County, California. The map displays the boundaries of zones of required investigation for liquefaction and earthquake-induced landslides over an area of approximately 30 square miles at a scale of 1 inch = 2,000 feet. Los Padres National Forest land covers more than half of the quadrangle. The rest of the area was evaluated for seismic hazards zoning.

The Whitaker Peak Quadrangle lies in northwestern Los Angeles County about 43 miles northwest of the Los Angeles Civic Center. A small area in the southwestern corner is within Ventura County. There are no incorporated cities but residential development is expanding into the southeastern corner where the community of Castaic extends west of Interstate Highway 5 near the mouth of Violin Canyon. Elderberry Forebay, an arm of Castaic Lake on the State Water Project, occupies Castaic Creek canyon near the eastern boundary. Contrasting geologic settings on opposite sides of the San Gabriel Fault Zone fault, which crosses the entire quadrangle, control the local topography. Near Castaic Lake, siltstone and clay shale strata host abundant landslides. West of the fault, mountainous terrain dominates the region. The northern third of the map area is underlain by a part of the Ridge Basin. Elevations range from 1,080 feet in Canton Canyon at the southwestern corner to 4,148 feet at Whitaker Peak near the western boundary. Strands of Interstate Highway 5, the primary transportation route, cross the entire quadrangle.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

In the Whitaker Peak Quadrangle the liquefaction zone is restricted to short stretches in the bottoms of Castaic, Violin, and Marple canyons. The combination of deeply dissected terrain and weak rocks has produced widespread and abundant landslides. These conditions, when subjected to the geologic and geotechnical anaylsis used in this study, result in approximately 73 percent of the study area lying within the earthquake-induced landslide hazard zone for the Whitaker Peak Quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Whitaker Peak 7.5-Minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Whitaker Peak 7.5-Minute Quadrangle, Los Angeles County, California

By
Allan G. Barrows and Ralph C. Loyd

California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC).

The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Whitaker Peak 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles region was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, including areas in the Whitaker Peak Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Whitaker Peak Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Whitaker Peak Quadrangle covers approximately 62 square miles in northwestern Los Angeles County about 43 miles northwest of the Los Angeles Civic Center. A one-half square mile area in the extreme southwestern corner lies within Ventura County. About half of the land within the quadrangle is within the Los Padres National Forest.

Seismic hazards zoning concentrated primarily upon the non-national forest land that covers the other half of the quadrangle. There are no incorporated cities within the quadrangle. Residential development is expanding into the southeastern corner where the community of Castaic extends along the hills west of Interstate Highway 5 near the mouth of Violin Canyon. Elderberry Forebay, an arm of Castaic Lake, which is a reservoir on the State Water Project, occupies Castaic Creek canyon near the eastern boundary.

West of Interstate Highway 5, the northwest-striking San Gabriel Fault Zone crosses the entire quadrangle. Contrasting geologic settings control the local topography within the map area. Near Castaic Lake, siltstone and clay shale strata are typically covered with grass or scattered brush and host abundant landslides. West of the San Gabriel Fault in Palomas Canyon rugged, brushy, mountainous terrain dominates the region. The center of the northern third of the map area is underlain by a part of the Ridge Basin, wherein thin-bedded lakebeds are deeply dissected. Although all of the major creeks within the quadrangle drain toward the south, a drainage divide near Oak Flats along old, bypassed, U.S. Highway 99 corresponds with a northward-flowing tributary of Piru Creek. Elevations range from 1,080 feet in Canton Canyon at the southwestern corner to 4,148 feet at Whitaker Peak near the western boundary.

Strands of Interstate Highway 5, the primary transportation route, cross the entire quadrangle from south to north. The Old Ridge Route, Templin Highway, and unpaved forest service roads provide additional access to the high country.

GEOLOGY

Bedrock and Surficial Geology

The geologic map used in this evaluation was obtained as a paper map from the Dibblee Geological Foundation (Dibblee, 1997) and digitized by CGS staff for this study. CGS geologists then modified contacts between bedrock and surficial units through the use of air-photo interpretation and field reconnaissance.

Bedrock exposed in areas subject to seismic hazard zoning within the Whitaker Peak Quadrangle consists of gneissic and granitic crystalline basement rocks along with assorted Tertiary sedimentary strata. The sedimentary units include upper Cretaceous to Paleocene marine sandstone and conglomerate of the San Francisquito Formation, late Miocene marine sandstone and shale of the Castaic Formation, late Miocene marine, lacustrine, and fluvial deposits of the Ridge Basin Group, middle Miocene shale of the Monterey Formation, middle Miocene shale and siltstone of the Sisquoc Formation, upper Miocene to lower Pliocene claystone of the Towsley Formation, Pliocene marine claystone and siltstone of the Pico Formation, and Plio-Pleistocene fluvial conglomerate, claystone, and sandstone of the Saugus Formation (Dibblee, 1997).

Quaternary surficial deposits consist mainly of older to younger canyon floor and stream channel deposits. They were mapped by Dibblee (1997) in Marple, Violin, Oak Flat, Castaic, and numerous smaller canyons. The map depicts Quaternary deposits as older alluvium (Qoa), canyon floor alluvium (Qa), and gravelly stream channel deposits (Qg). It is important to note that the texture and thickness of these deposits vary considerably among and even within individual canyons depending on local bedrock characteristics and prevalent stream energy conditions. Detailed observations regarding the nature and distribution of Quaternary sediments within specific canyon reaches in the quadrangle were made by Barrows during fieldwork for unpublished mapping.

Structural Geology

The Whitaker Peak Quadrangle lies within the extreme easterly portion of the East Ventura Basin (Yeats and others, 1985; 1994), an elongate west-trending synclinal basin whose axis lies generally along the Santa Clara River Valley, south of the town of Castaic. The East Ventura Basin is truncated by the San Gabriel Fault within the Whitaker Peak Quadrangle, however smaller Miocene-age basins were formed, namely the Ridge Basin, which is a dominant structural feature in the study area. Overall structural configuration of the bedrock materials indicate relatively deep shortening of the Miocene sedimentary units, accommodated by relatively shallow fold belts, and complex intertonguing of the Violin Breccia and Ridge Basin sediments within the Ridge Basin Syncline, which is located parallel to, and exclusively east of the San Gabriel Fault.

In addition to folding, the Tertiary units have been subjected to rotation (possible drag folding from the San Gabriel Fault), resulting in some complex fold structures. Although the San Gabriel fault segment within this quadrangle does not meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by CGS, the San Gabriel Fault is considered to be a major potential seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). Evidence of Holocene surface rupture, such as that found in the Newhall Quadrangle to the southeast (DOC, 1995), has not been found in the Whitaker Peak Quadrangle.

GROUND WATER

Depth to ground water is a key factor governing liquefaction hazard. Ground-water saturation reduces the effective normal stress acting on loose, sandy sediments, thus lowering the resistance of sediments to loss of strength when pore-water pressure increases during ground shaking associated with earthquakes. Liquefaction of subsurface sedimentary layers can result in ground failure that can damage structures at the surface through differential settlement or lateral spreading, particularly if liquefaction occurs at depths within 40 feet or less from the ground surface.

Natural processes and human activities over seasons, years, and decades cause large fluctuations in ground-water levels. These fluctuations generally make it nearly impossible to specify what specific ground-water conditions might exist when future earthquakes cause significant ground shaking. To address this uncertainty, CGS develops ground-water maps that show depths to historically shallowest levels recorded from water wells and boreholes drilled over the past century. The evaluations are based on first-encountered water noted in the borehole logs. Water depths from boreholes known to penetrate confined aquifers are not used. The resultant map, which is based on measurements recorded over the past century or more, differs considerably from conventional ground-water maps that are based on measurements collected during a shorter time span such as single season or year.

Historically shallowest depths to ground water in alluviated canyon regions of the Whitaker Peak Quadrangle are presented on Plate 1.2. Depth measurements to historically high ground-water levels in canyon areas are generally shallow, commonly 10 feet or less. Such shallow ground-water conditions commonly exist in these depositional environments because canyon lowlands tend to receive and accumulate heavy runoff and near-surface ground water derived from surrounding highlands.

PART II

LIQUEFACTION POTENTIAL

Liquefaction can occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), who apply a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates following criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size of a soil also influences susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. CGS's qualitative assessment of liquefaction susceptibility relative to various geologic units and depth to ground water is summarized in Table 1.1.

Geologic Map Unit	**Sediment Type**	**Environment of Deposition**	**Consistency**	**Susceptible to Liquefaction?**
Qa, Qg	gravel, sand, silt, clay	canyon floor, stream channel	very loose to loose	Yes*
Qoa	gravel	fluvial	compact	No

* depending on clay/cobble content and thickness.

Table 1. 1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units in the Whitaker Peak Quadrangle.

LIQUEFACTION OPPORTUNITY

Analysis of in-situ liquefaction potential requires assessment of liquefaction opportunity. Liquefaction opportunity is the estimation of the severity of expected future ground shaking over the region at a specific exceedance probability and exposure time (Real, 2002). The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis of liquefaction potential is the magnitude that contributes most to the calculated PGA for an area.

PGAs of 0.53g to 0.70g (for alluvium conditions), resulting from predominant earthquakes of magnitudes from 6.6 to 7.8, were used for liquefaction analyses for the Whitaker Peak Quadrangle. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (section 3) of this report for additional discussion of ground motion characterization.

Quantitative Liquefaction Analysis

No quantitative analysis of liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990, Youd and Idriss, 1997) was performed in the evaluation of the Whitaker Peak Quadrangle because no useful geotechnical borehole logs were available. Consequently, other criteria adopted by the State Mining and Geology Board (DOC 2000) were applied in the seismic hazard mapping for liquefaction (see following section).

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Whitaker Peak Quadrangle is summarized below.

Areas of Past Liquefaction

Documented reports of liquefaction or evidence of paleo-liquefaction have not been found for the Whitaker Peak Quadrangle. However, ground fractures, differential settlement, and lateral spreading in part consistent with earthquake-induced liquefaction was mapped in similar young alluvial deposits10 miles south in the Santa Clara River valley, Tapo Canyon, and Potrero Canyon by Rymer and others (2001) following the1994 Northridge Earthquake.

Artificial Fills

Use of artificial fill in areas large enough to show at the scale of mapping in the Whitaker Peak Quadrangle consist of engineered fill for dams, home development, and freeway/road construction. Since these fills are generally considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Geotechnical logs of boreholes in the Whitaker Peak Quadrangle were not found during the data collection phase of this study.

Areas with Insufficient Existing Geotechnical Data

Canyon Floors: Useful geotechnical borehole data in alluviated areas (canyon floors) of the Whitaker Peak Quadrangle were not located during the course of this study. However, information based on field observations concerning the nature and distribution of canyon-floor Quaternary sedimentary deposits was available. This information enabled a more confident application of SMGB criteria item number four during the zoning process because many of the canyon-floor deposits were removed from zoning consideration based on textural and thickness characteristics observed in the field.

In all, three areas in the Whitaker Peak Quadrangle are designated zones of required investigation based largely on SMGB criteria item 4a. From north to south, these are sand and gravel deposits in Castaic Canyon at the northern end of Elderberry Forebay, sandy/silty sediments deposited along an approximately one-mile segment of Violin Canyon, and sandy/silty sediments deposited at and near the intersection of Marple and Violin canyons in the southeastern corner of the quadrangle.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Whitaker Peak 7.5-Minute Quadrangle, Los Angeles County, California

By
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California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the

American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Whitaker Peak 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Whitaker Peak Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Whitaker Peak Quadrangle, for more information on the delineation of liquefaction zones.

A significant portion of the Whitaker Peak Quadrangle lies within the boundaries of the Los Padres National Forest and is not likely to be developed. However, some private landholdings, which could be developed in the future, lie within and near the edge of the National Forest boundary. For this reason, the earthquake-induced landslide study area in the Whitaker Peak Quadrangle extends into the National Forest in places, but does not include all of it.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Whitaker Peak Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Whitaker Peak Quadrangle covers approximately 62 square miles in northwestern Los Angeles County about 43 miles northwest of the Los Angeles Civic Center. A one-half square mile area in the extreme southwestern corner lies within Ventura County. About half of the land within the quadrangle is within the Angeles National Forest (Administered by the Los Padres National Forest). Seismic hazards zoning concentrated primarily upon the non-national forest land that covers the remaining half of the quadrangle. There are no incorporated cities within the quadrangle. Residential development is expanding into the southeastern corner of the quadrangle, where the community of Castaic extends along the hills west of Interstate Highway 5 near the mouth of Violin Canyon, and to the east of Interstate Highway 5, southwest of Castaic Dam. Additionally, Elderberry Forebay, an arm of Castaic Lake, which is a reservoir of the State Water Project, occupies Castaic Creek canyon near the eastern boundary.

West of Interstate Highway 5, the northwest-striking San Gabriel Fault Zone crosses the entire quadrangle. Contrasting geologic settings control the local topography within the map area. Near Castaic Lake, siltstone and clay shale strata are typically covered with grass or scattered brush and host abundant landslides. West of the San Gabriel Fault in Palomas Canyon rugged, brushy, mountainous terrain dominates the region. The center of the northern third of the map area is underlain by a part of the Ridge Basin, wherein thin-bedded lakebed deposits are deeply dissected. Although all of the major creeks within the quadrangle drain toward the south, a drainage divide near Oak Flats along old, bypassed, U.S. Highway 99 corresponds with a northward-flowing tributary of Piru Creek. Elevations range from 1,080 feet in Canton Canyon at the southwestern corner to 4,148 feet at Whitaker Peak near the western boundary.

Strands of Interstate Highway 5, the primary transportation route, cross the entire quadrangle from south to north. The Old Ridge Route, Templin Highway, and unpaved forest service roads provide additional access to the high country.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Whitaker Peak Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1956 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1956 in the hilly portions of the quadrangle were updated to reflect the new topography. A DEM reflecting this recent grading was obtained from an airborne interferometric radar sensor flown in 2001, with an estimated vertical accuracy of approximately 1.5 meters (Intermap Corporation, 2002). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. The DEM used for the graded areas within the Whitaker Peak Quadrangle underwent additional processing to remove these types of artifacts (Wang and others, 2001). Nevertheless, the final hazard zone map was checked for potential errors resulting from the use of the radar DEM and corrected if necessary. Graded areas where the radar DEM was applied are shown on Plate 2.1

A slope map was made from both the USGS and the Intermap radar DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The manner in which the slope maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The bedrock geologic map used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1997) and digitized by CGS staff for this study. Bedrock units are described in detail in this section. Surficial geologic units are briefly described here and are discussed in more detail in Section 1, Liquefaction Evaluation Report.

CGS geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory created during this study would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S. Geological Survey 7.5-minute quadrangle. Bedrock geology was modified in some areas to reflect more recent mapping. In addition, geologic mapping by Barrows (unpublished, 1986) was consulted. Air-photo interpretation and field reconnaissance was performed to assist in adjusting contacts between bedrock and surficial geologic units and to review geologic unit lithology and geologic structure. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

Bedrock in the study area within the Whitaker Peak Quadrangle consists of Precambrian crystalline basement rocks and a variety of Tertiary sedimentary strata. The Tertiary units include the San Francisquito, Castaic, Ridge Basin Group, Monterey, Sisquoc, Towsley, and Pico formations. In addition, the Pliocene to Pleistocene Saugus Formation also occurs in the quadrangle. The San Gabriel Fault, which traverses the Whitaker Peak Quadrangle from the southeast to the northwest, forms a significant tectonic boundary with dissimilar bedrock assemblages on opposite sides.

Geologic Units East of the San Gabriel Fault

The oldest geologic unit east of the San Gabriel Fault is the upper Cretaceous to Paleocene San Francisquito Formation (map symbol Tsfs; Dibblee, 1967; Kooser, 1982). This unit is a tan, thick-bedded to massive sandstone with local conglomerate lenses and thin interbeds of gray, micaceous shale, predominantly marine. This formation also includes a gray to brown conglomerate unit (map symbol Tsfc) that contains clasts of granite and gray andesite porphry in a sandstone matrix. The type locality for this formation is located north of the Castaic power plant, in the northeastern portion of the study area.

An angular unconformity separates the San Francisquito Formation from late Miocene Castaic Formation. Castaic Formation (Tcs) consists of light gray, fine- to medium-grained, shallow marine sandstone (Crowell, 1954; 1982) and a gray clay shale member (Tc), which is silty, micaceous, weathers crumbly and contains thin claystone and sandstone interbeds. The type locality for the Castaic Formation is in Castaic Canyon, a portion of which is now occupied by Lake Castaic in the southeast corner of the quadrangle. Also included is a light brown basal conglomerate (Tcgs) that is moderately hard with sandstone and granite clasts. These units were deposited during shallow marine transgressive events, restricted by the San Gabriel Fault scarp (Crowell, 1954; Link 1982). Additionally, the Violin Breccia of Crowell (1954; 1982) discussed below, intertongues eastward from the San Gabriel Fault, with Tc and Tcs, located across the central portion of the map area.

Conformably overlying the Castaic Formation is the Ridge Basin Group of Crowell (1954; 1982). The units of the Ridge Basin Group consist of marine, lacustrine and fluvial sediments that interfinger, were deposited during late Miocene time, and are only moderately lithified. The most prevalent unit is the Violin Breccia (map symbol Tvib) which is crudely bedded and contains angular fragments of gneissic and granitic rocks. The Violin Breccia is interpreted to have developed along the San Gabriel Fault as a result of rapid uplift and strike-slip movement of source terranes (Crowell, 1954; 1982). Additionally, rapid deposition of material from surrounding source areas east of the fault occurred during several stages of evolution of the fault system and the surrounding sedimentary basins (Stitt and Yeats, 1982).

Other members within the Ridge Basin Group include the Peace Valley and Ridge Route formations. The Peace Valley Formation (Tpv) consists of a gray, brackish marine to lacustrine siltstone and claystone and is well bedded and crumbly where weathered (Irvine, 1977;Crowell, 1982). The Ridge Route Formation (Trr) is a light gray to tan, fluvial arkosic sandstone, with interbeds of clayey shale (Crowell, 1982). This formation exhibits some soft sediment deformation features, and crops out in the central and north half of the map area.

Geologic Units West of the San Gabriel Fault

The oldest rocks west of the San Gabriel Fault are Precambrian(?) gneiss (gn), composed of bands of quartz and feldspar alternating with gray to black biotite-rich bands. Granitic rocks commonly intrude this unit. Although the gneiss is moderately to severely fractured, it forms steep terrain and is exposed as a linear strip adjacent to the San Gabriel Fault in the central portion of the map.

The oldest Tertiary formation west of the San Gabriel Fault is the Miocene Monterey Formation (Dibblee, 1997), also mapped as Modelo Formation by earlier workers (Eldridge and Arnold, 1907). The Monterey Formation, which crops out in the southwestern corner of the quadrangle, includes a marine shale member (Tm) that is a thin-bedded, white weathering, platy, fissile shale with some calcareous beds; a lower shale unit (Tml), similar to the shale member but with increased calcareous content; a tan sandstone (Tmss), which is semi-friable, with thin interbeds of silty shale; and a crudely bedded conglomerate (Tmcg) which is locally known as the Devil Canyon conglomerate, which contains clasts of anorthosite, gneiss and porphyry, and is interpreted to have been deposited as near shore submarine fans.

Conformably overlying the Monterey Shale is the middle Miocene Sisquoc Formation (Tsq; Dibblee 1997; originally included in the Modelo Formation by Eldridge and Arnold (1907). It consists of grayish-brown, crumbly marine micaceous silty clay-shale to siltstone. Sisquoc Formation is somewhat siliceous, bedded, and, locally contains dolomitic lenses. Sisquoc Formation crops out in the same areas as the Monterey shale, and has experienced roughly the same degree of structural deformation.

The upper Miocene to lower Pliocene Towsley Formation (Ttoc) is a gray, marine, micaceous claystone. This unit is crumbly, vaguely bedded and silty. A basal conglomerate member (Ttog), called the Hasley Conglomerate by Stitt (1986) and Yeats and others (1986), is exposed in outcrops between the clay shale member (Ttoc) and the underlying Sisquoc and Monterey formations in the southern part of the map. The conglomerate contains rounded cobbles and pebbles of mostly of granitic composition and scattered metavolcanic clasts in a sandy matrix.

Pliocene to Pleistocene bedrock units include the Pico and Saugus formations. The Pico Formation (Tp) is mostly Pliocene in age (Dibblee, 1997). The Pico Formation consists of light gray marine claystone and siltstone, with thin sandstone beds, and includes a tan pebbly sandstone member (Tps). Both of these units are exposed near Violin Canyon and Santa Felicia Canyon in the southeastern corner of the map.

The Saugus Formation (QTs) overlies the Pico Formation and is composed of interbedded light gray non-marine pebble conglomerate with sandstone and claystone, deposited under primarily fluvial conditions. The Saugus Formation crops out in the extreme southeastern corner of the map, near Romero Canyon.

Younger Quaternary surficial deposits consist of older and younger valley and river deposits, gravel channel deposits, and active stream deposits (Qoa, Qa and Qg). They cover the floors of Marple Canyon, Violin Canyon, Oak Flat Canyon, Castaic Canyon and other smaller canyons. Pleistocene to Holocene landslide deposits are widespread throughout the Whitaker Peak Quadrangle, especially in the fine-grained Tertiary sedimentary units such as the Monterey, Castaic, Sisquoc, Peace Valley (Ridge Basin Group), Towsley and Pico formations, where bedding planes are inclined in the same direction as the slope (a dip slope). Landslide deposits are not shown on the bedrock/Quaternary geologic map, but are included on a separate landslide inventory map (Plate 2.1). Modern fill (af), likely cut-and-cast fill from forest road development, and more recently engineered fill from highway, residential and commercial development, occurs in scattered places across the map. A more detailed discussion of the Quaternary deposits in the Whitaker Peak Quadrangle can be found in Section 1.

Structural Geology

The Whitaker Peak Quadrangle lies within the extreme easterly portion of the East Ventura Basin (Yeats and others, 1985; 1994), an elongate west-trending synclinal basin whose axis lies generally along the Santa Clara River Valley, south of the town of Castaic. The East Ventura Basin is truncated by the San Gabriel Fault within the Whitaker Peak Quadrangle, however smaller Miocene-age basins were formed, namely the Ridge Basin, which is a dominant structural feature in the study area. Overall structural configuration of the bedrock materials indicate relatively deep shortening of the Miocene sedimentary units, accommodated by relatively shallow fold belts, and complex intertonguing of the Violin Breccia and Ridge Basin sediments within the Ridge Basin Syncline, which is located parallel to, and exclusively east of the San Gabriel Fault.

In addition to folding, the Tertiary units have been subjected to rotation (possible drag folding from the San Gabriel Fault), resulting in some complex fold structures. Although the San Gabriel fault segment within this quadrangle does not meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by CGS, the San Gabriel Fault is considered to be a major potential seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). Evidence of Holocene surface rupture, such as that found in the Newhall Quadrangle to the southeast (DOC, 1995), has not been found in the Whitaker Peak Quadrangle.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Whitaker Peak Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published and unpublished landslide mapping (Weber, 1979; Barrows, 1986; Yeats and others, 1986; Los Angeles County, 1994; Harp and Jibson, 1995; and consultant reports on file at Los Angeles County). Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the landslide zoning as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides are widespread and relatively abundant in the Whitaker Peak Quadrangle. Moderately large landslides are common in the southwestern map area, especially within the claystone and siltstone units (Tm) of the Monterey Formation. Landslides are also common within the friable sandstone unit of the Pico Formation (Tps). Other landslides exist within most of the remaining mapped formations, including the gray micaceous siltstone of the Towsley Formation (Ttoc), the micaceous clay shale of the Sisquoc Formation (Tsq), the gray clay shale of the Peace Valley Formation (Tpv), and the gray, micaceous clay shale of the Castaic Formation (Tc). Rock falls and shallow rock slides occur on some slopes comprised of the Saugus Formation, represented as gravel conglomerate, sandstone and claystone (QTs).

Landslides in the mapped area range from numerous debris slides to rock slides and include rotational and large translational landslides, some of which are old and deeply eroded. Landslide identification in the Whitaker Peak Quadrangle is somewhat difficult in particular bedrock units, due to the folded orientation of the bedrock, and effects of weathering on the geomorphic expression of landslide features. Individual small debris-flow tracks and deposits were not mapped for this study due to map scale limitations.

The quadrangle area was moderately impacted by the M 6.7 Northridge earthquake of January 17, 1994. Shaking was moderately intense in the region because the faulting that triggered the event was inclined upward from the focal area, toward much shallower depths in this region. Vertical and horizontal ground motion, as measured in the nearby Newhall area was very strong (CSMIP Station 23279 in Shakal and others, 1994, p. 46). The Northridge event triggered only very minor slope failures in the Whitaker Peak Quadrangle. Areal extent of landslide occurrence and features from the Northridge event is discussed in separate reports (Barrows and others, 1995; Harp and Jibson, 1995).

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Whitaker Peak Quadrangle geologic map were obtained entirely from the Los Angeles County Materials Engineering Division (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants within the study area are shown on Plate 2.1. Shear tests from the adjoining Val Verde, Newhall and Warm Springs Mountain quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Whitaker Peak Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group, are summarized in Table 2.1. A phi of 35 degrees was assigned to the hard rocks in Group 1 on the basis of field observations and average phi values for gneiss and breccia from engineering geology textbooks, since no shear strengths were found for these units. For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. For the Whitaker Peak Quadrangle, six direct shear tests of landslide slip surface materials were obtained from the adjacent Val Verde Quadrangle and the results are summarized in Table 2.1.

	WHITAKER PEAK QUADRANGLE SHEAR STRENGTH GROUPS						
	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	gn		35	35		gn, Tmcg	35
						Tsfc, Tvib	
GROUP 2	af	4	32	31/32	313/260	Qg, Qoa	31
	Qa	32	30/31			Tcgs, Tm	
	QTs	108	31/32			Tma, Tml	
	Tp	12	32/31			Tmss, Trr	
						Tcs, Tsc, Tsfs	
						Tsp, Tspc	
						Tsqs, Ttog	
GROUP 3	Tps	7	28/25	27/28	570/420	Tpv, Tsq	27
	Tca/Tc	47	27/28			Ttoc	
GROUP 4	Qls	6	13	13	508/325		13
	Geologic formation name abbreviations for strength groups are from Dibblee, 1997.						

Table 2.1. Summary of the Shear Strength Statistics for the Whitaker Peak Quadrangle.

SHEAR STRENGTH GROUPS FOR THE WHITAKER PEAK 7.5-MINUTE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
gn	af, Qa, Qg	Tca/Tc	Qls
Tmcg	Qoa, QTs	Tps	
Tsfc	Tcgs, Tcs	Tpv	
Tvib	Tm, Tma, Tml	Tsq	
	Tmss, Tp	Ttoc	
	Trr, Tsc		
	Tsfs, Tsp		
	Tspc, Tsqs		
	Ttog		

Table 2.2. Summary of Shear Strength Groups for the Whitaker Peak Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity". For the Whitaker Peak Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10 percent probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.6 to 7.8
Modal Distance:	5.3 to 19.7 km
PGA:	0.51g to 0.75g

The strong-motion record selected for the slope stability analysis in the Whitaker Peak Quadrangle was the Southern California Edison (SCE) Lucerne record from the 1992 magnitude 7.3 Landers, California, earthquake. This record had a source to recording site distance of 1.1 km and peak ground acceleration (PGA) of 0.80g. Although the distance and PGA values of the Lucerne record do not fall within the range of all the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm are used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.14, 0.18, and 0.24 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Whitaker Peak Quadrangle.

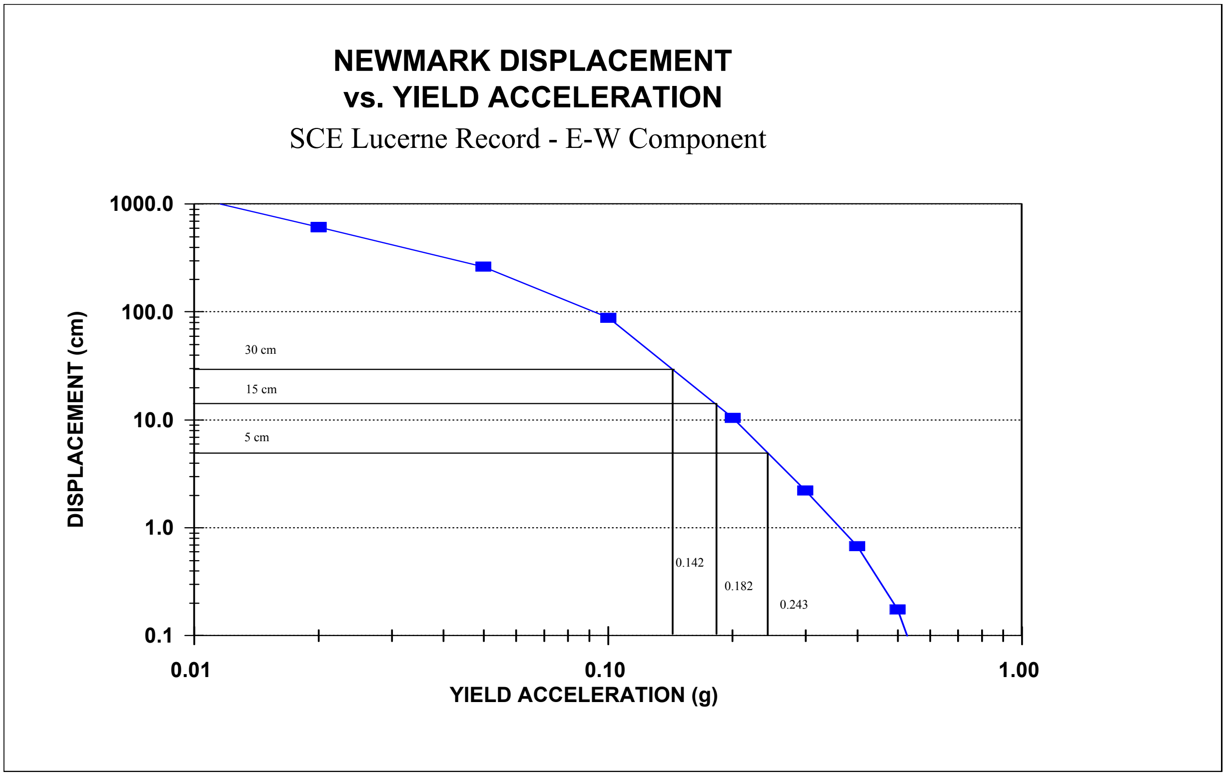

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1992 Landers Earthquake SCE Lucerne Record.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure, α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.14 g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3).

2. Likewise, if the calculated yield acceleration fell between 0.14 g and 0.18 g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3).

3. If the calculated yield acceleration fell between 0.18 g and 0.24 g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3).

4. If the calculated yield acceleration was greater than 0.24 g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3).

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

WHITAKER PEAK QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (Percent Slope)								
		I	II	III	IV	V	VI	VII	VIII	IX
		0-10	10-15	15-28	28-36	36-38	38-44	44-46	46-53	>53
1	31	VL	VL	VL	VL	L	L	L	M	H
2	27	VL	VL	VL	L	L	M	H	H	H
3	13	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Whitaker Peak Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas, and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

No earthquake-triggered landslides had been identified in the Whitaker Peak Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a number of relatively small, shallow slope failures in and adjacent to the Whitaker Peak Quadrangle (Harp and Jibson, 1995). Soil falls, debris falls, and debris slides occurred in poorly indurated or highly fractured sedimentary rock on steep slopes and along roadcuts. Seismic shaking also enhanced previously existing headscarps of massive bedrock landslides and created additional cracks on steep slopes and ridge tops. Landslides attributed to the Northridge earthquake covered approximately 176 acres of land in the quadrangle, which is 1 percent of the total area covered by the map. As indicated by the criteria for zoning, all of the Northridge earthquake triggered landslides are included in the landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 3 is included for all slope gradient categories. (Note: Geologic Strength Group 3 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 2 is included for all slopes steeper than 28 percent.

3. Geologic Strength Group 1 is included for all slopes steeper than 36 percent.

The combination of the existing landslides and the geologic and geotechnical analysis results in approximately 73 percent of the study area lying within the earthquake-induced landslide hazard zone for the Whitaker Peak Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Charles Nestle and Robert Larson from the Los Angeles County Materials Engineering Division provided assistance and access for collection of geologic material strength data, and review of geotechnical reports. Frank Glick from the Project Geology Section, Division of Engineering of the California Department of Water Resources provided information and maps on the Angeles Tunnel Project. Larry Cardozo, LaVonne Driver and James O'Tousa from the Ventura County Public Works office assisted in the search for geologic material strength data for the Ventura County portion of the Whitaker Peak Quadrangle. At CGS, Terilee McGuire, Lee Wallinder, and Bob Moscovitz provided GIS support. Barbara Wanish, Ross Martin, and Diane Vaughn prepared the final landslide hazard zone maps and the graphic displays for this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Los Angeles County	**37**
Val Verde Quadrangle	**157**
Warm Springs Mtn. Quadrangle	**10**
Newhall Quadrangle	**12**
Total Number of Shear Tests	**216**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Whitaker Peak 7.5-Minute Quadrangle, Los Angeles County, California

By

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California Geological Survey
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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

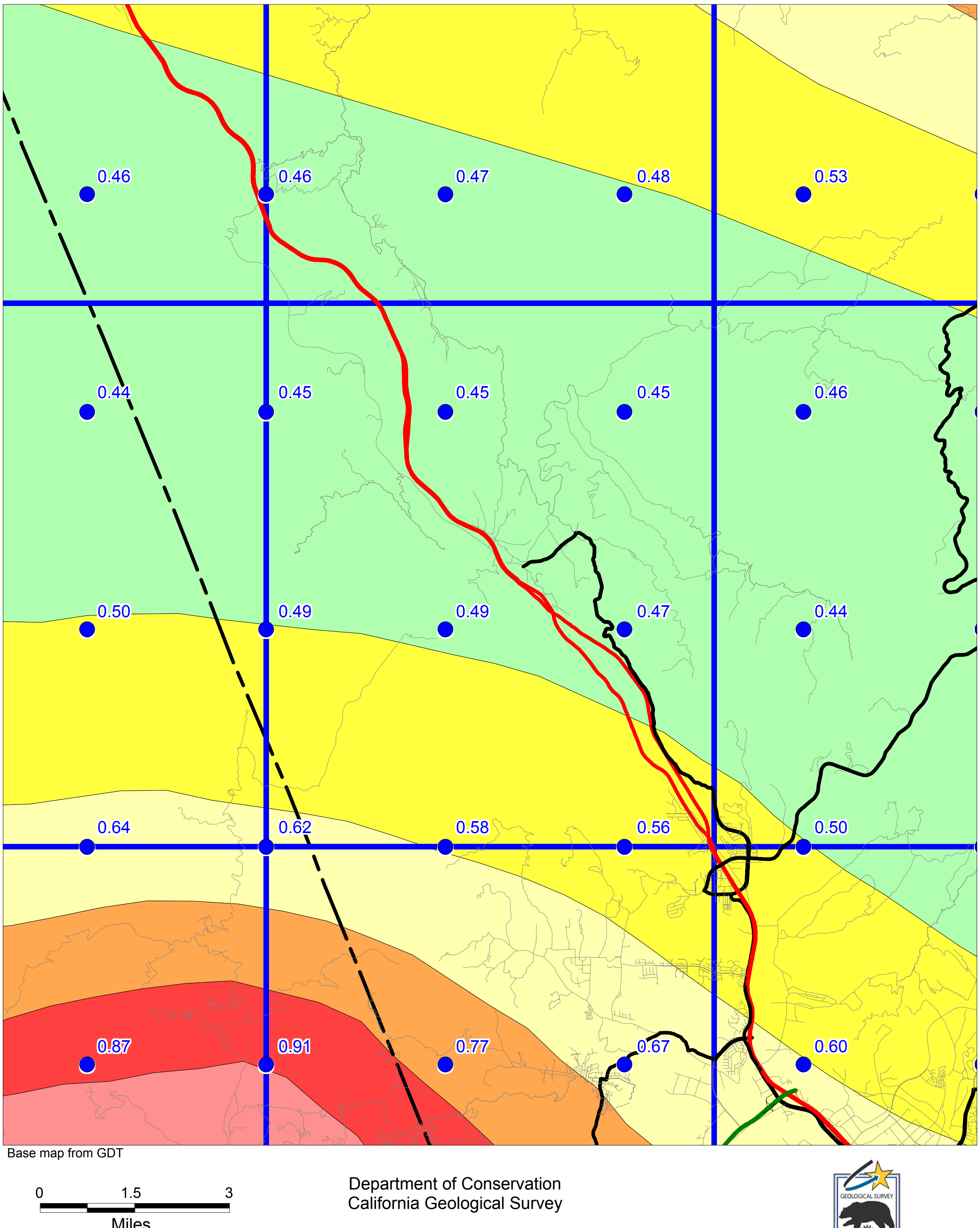
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight

WHITAKER PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
California Geological Survey

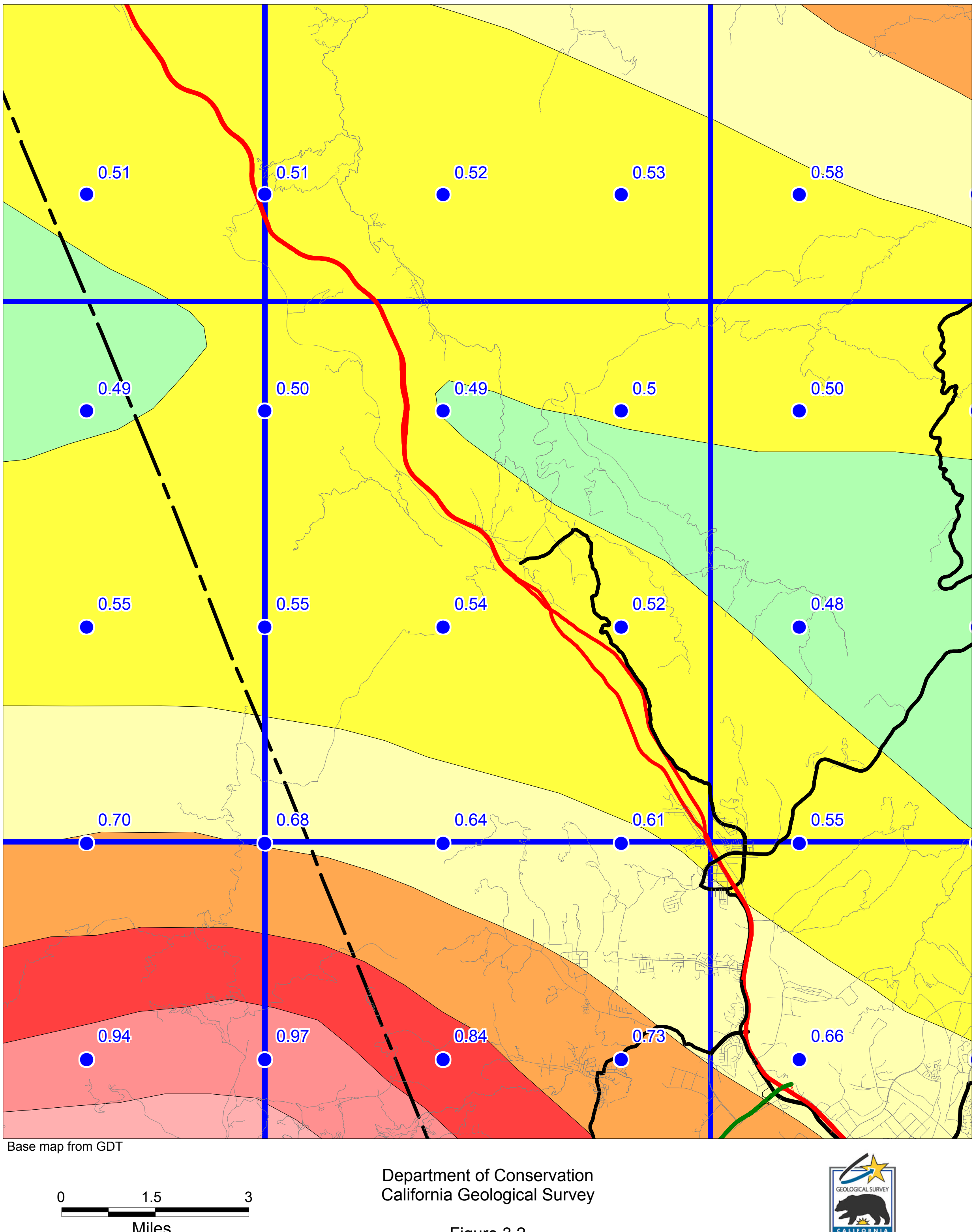
Figure 3.1

WHITAKER PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Department of Conservation
California Geological Survey

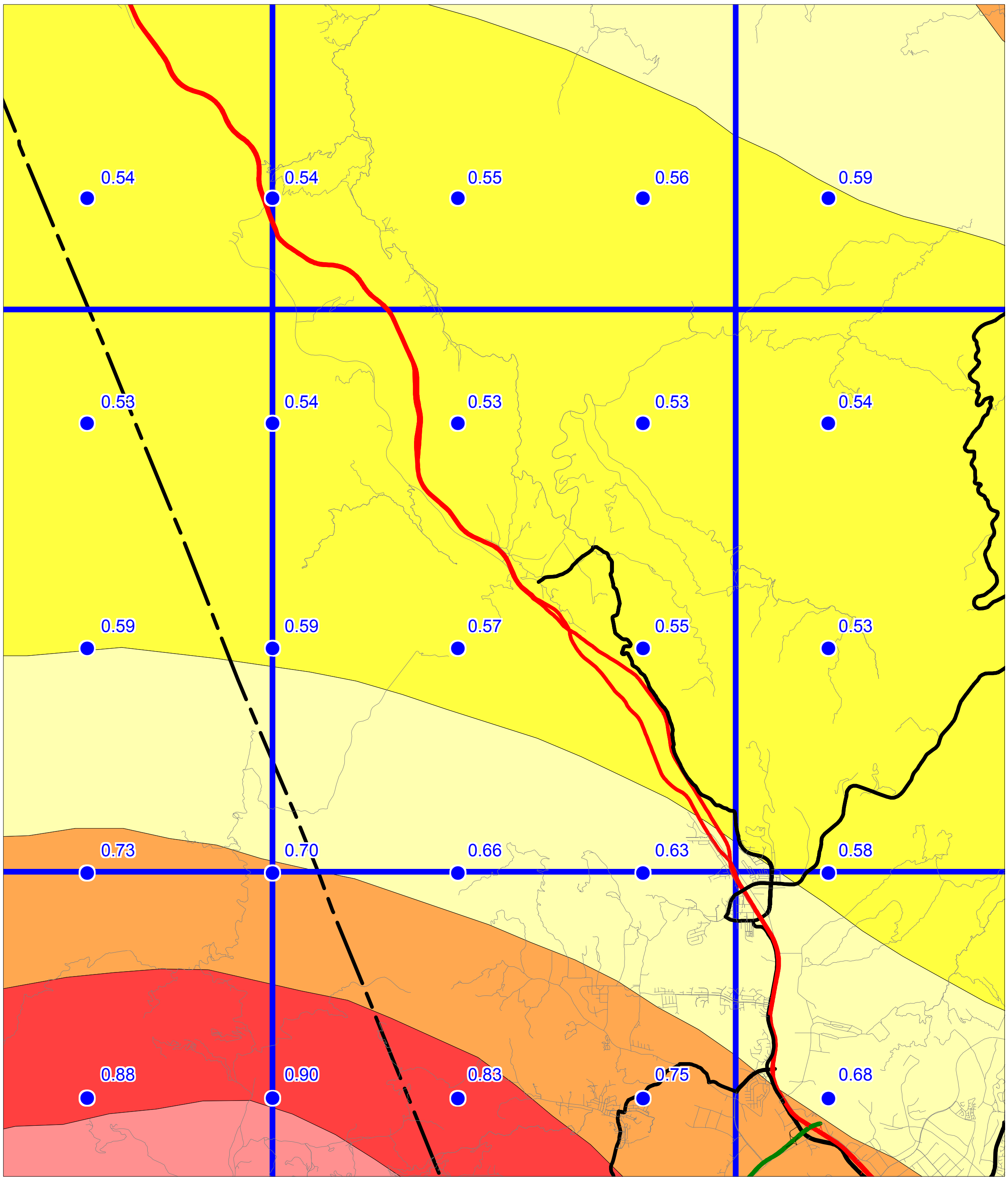
Figure 3.2

WHITAKER PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the "simplified Seed-Idriss method" of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a "magnitude-weighted" ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

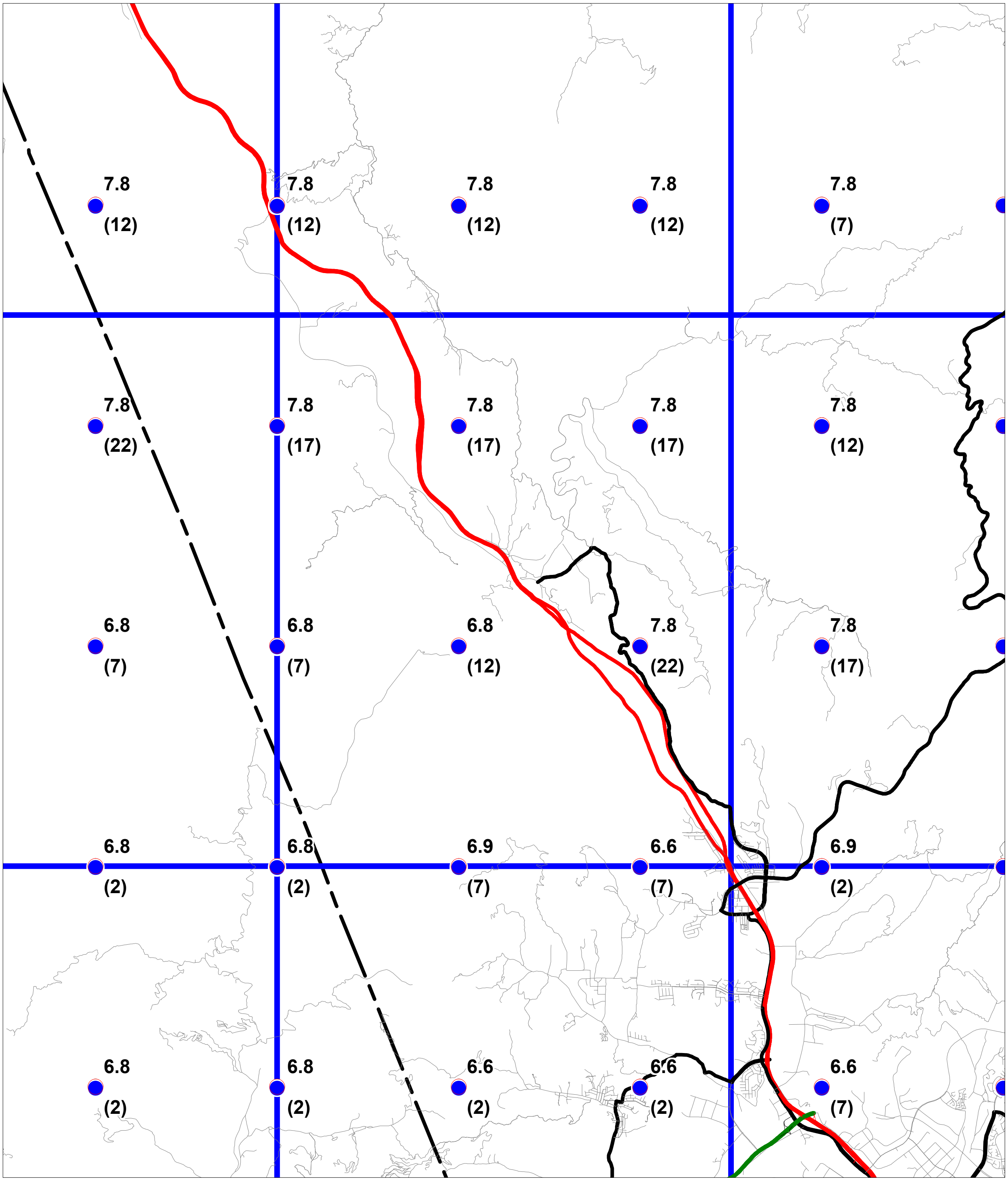
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

WHITAKER PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map from GDT

0 1.5 3
Miles

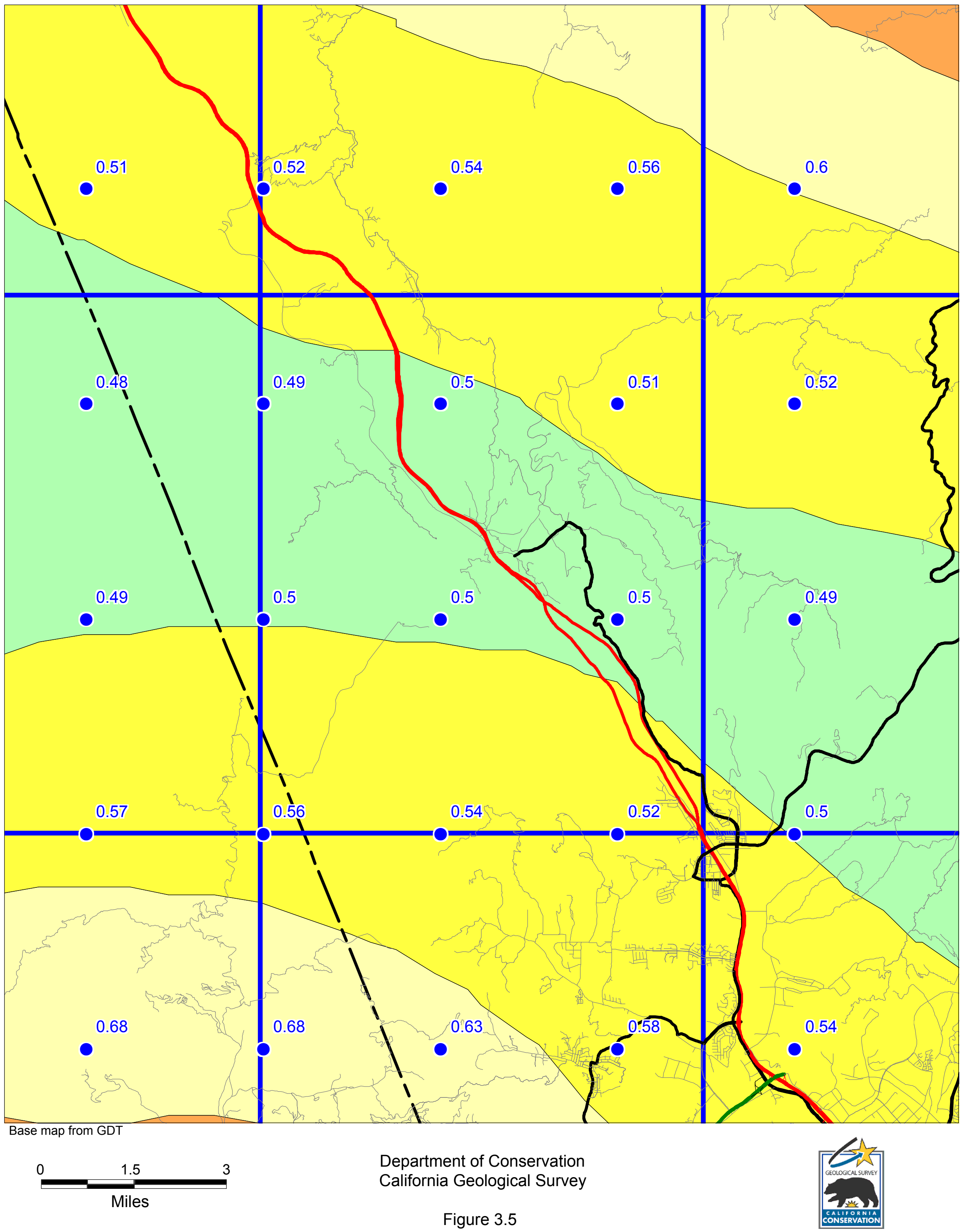
Department of Conservation
California Geological Survey
Figure 3.4

WHITAKER PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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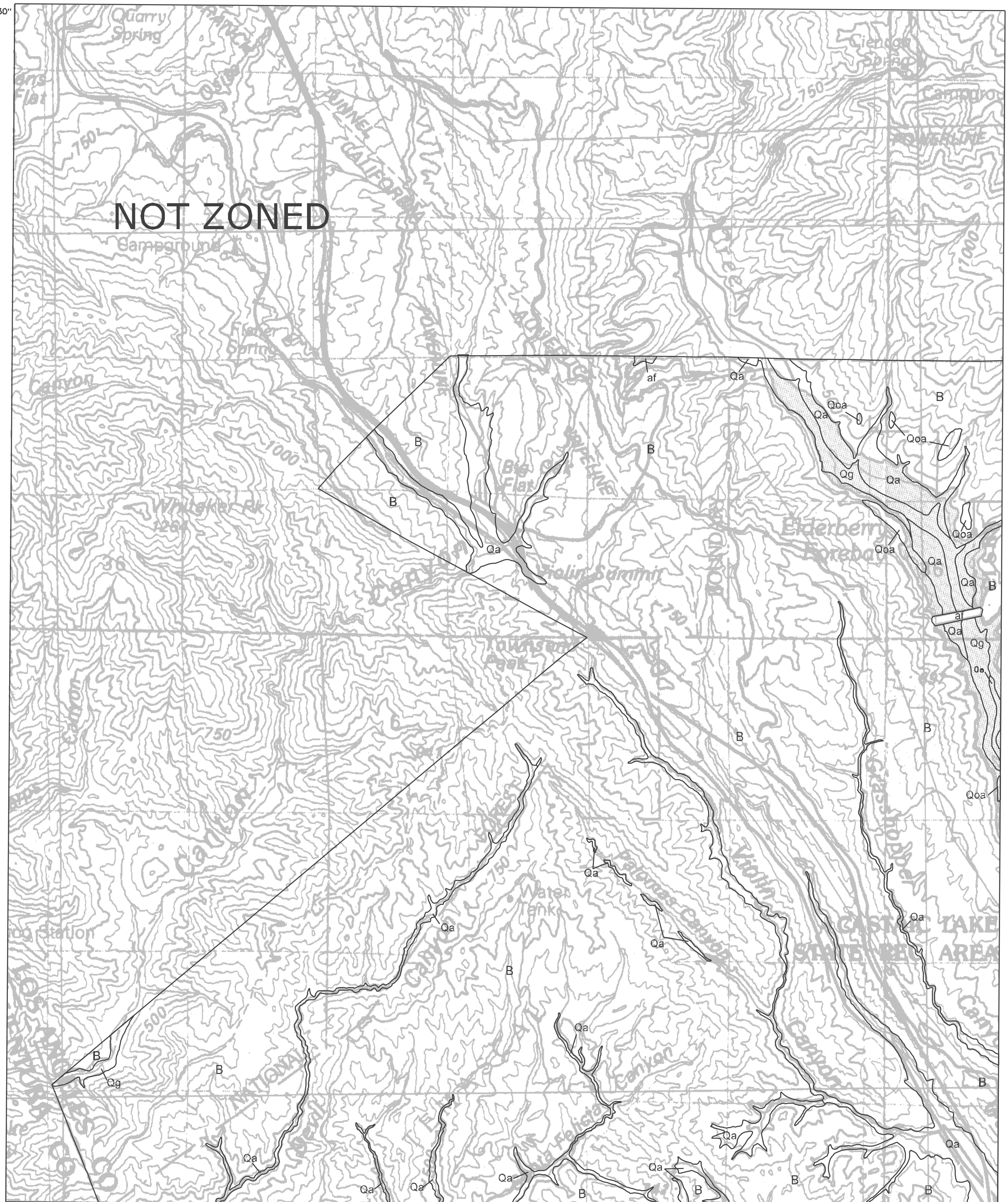
118° 45'

34° 37'30"



34° 30'

118° 37'30"

Base map enlarged from U.S.G.S. 30 x 60–minute series

WHITAKER PEAK QUADRANGLE

SCALE

1 .5 0 1 MILE

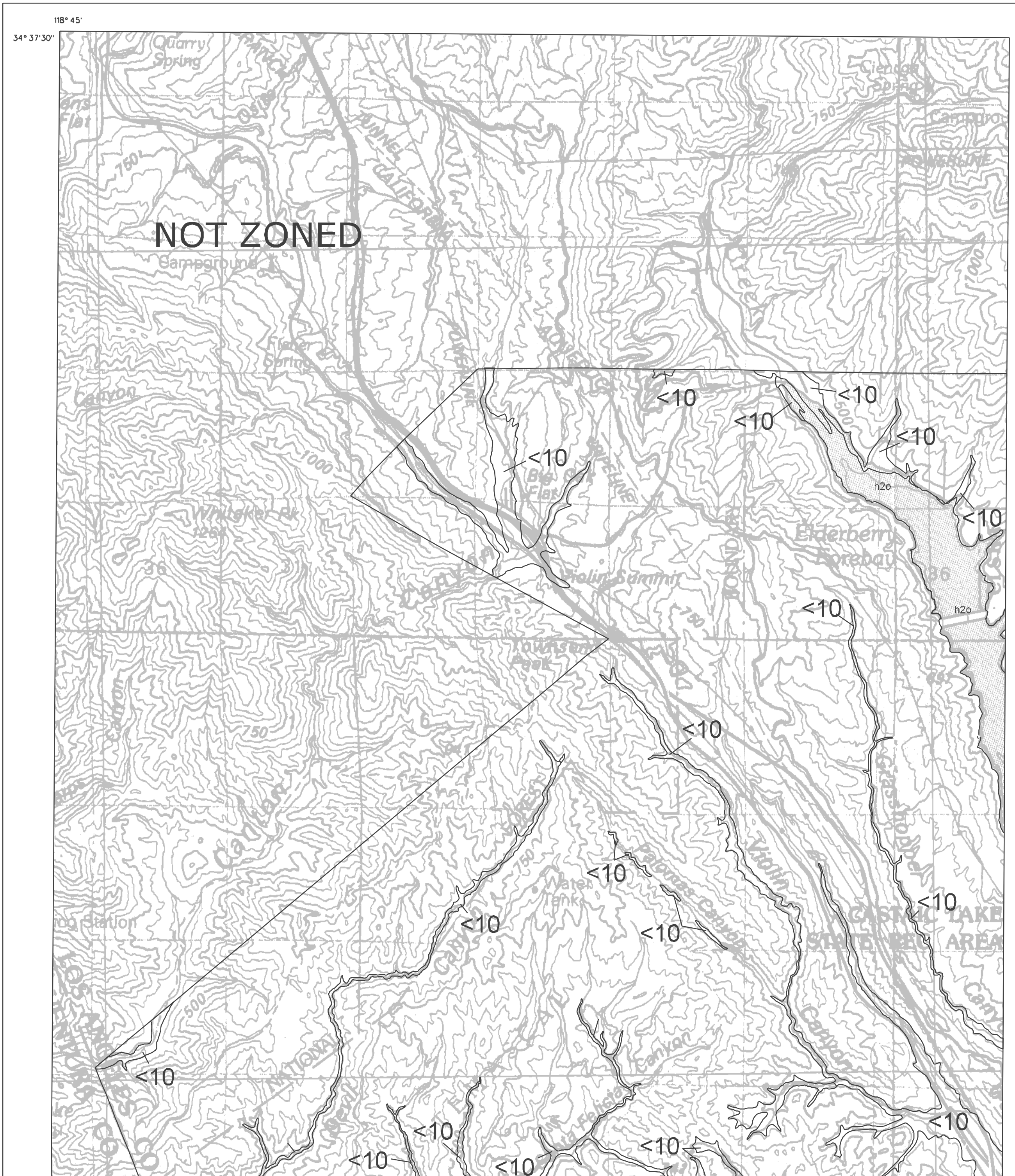
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

B = Pre-Quaternary bedrock.

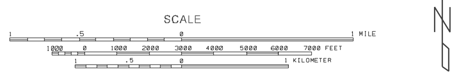
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

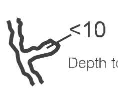
Plate 1.1 Quaternary Geologic Map of the Whitaker Peak 7.5-Minute Quadrangle, California.



Base map enlarged from U.S.G.S. 30 x 60–minute series

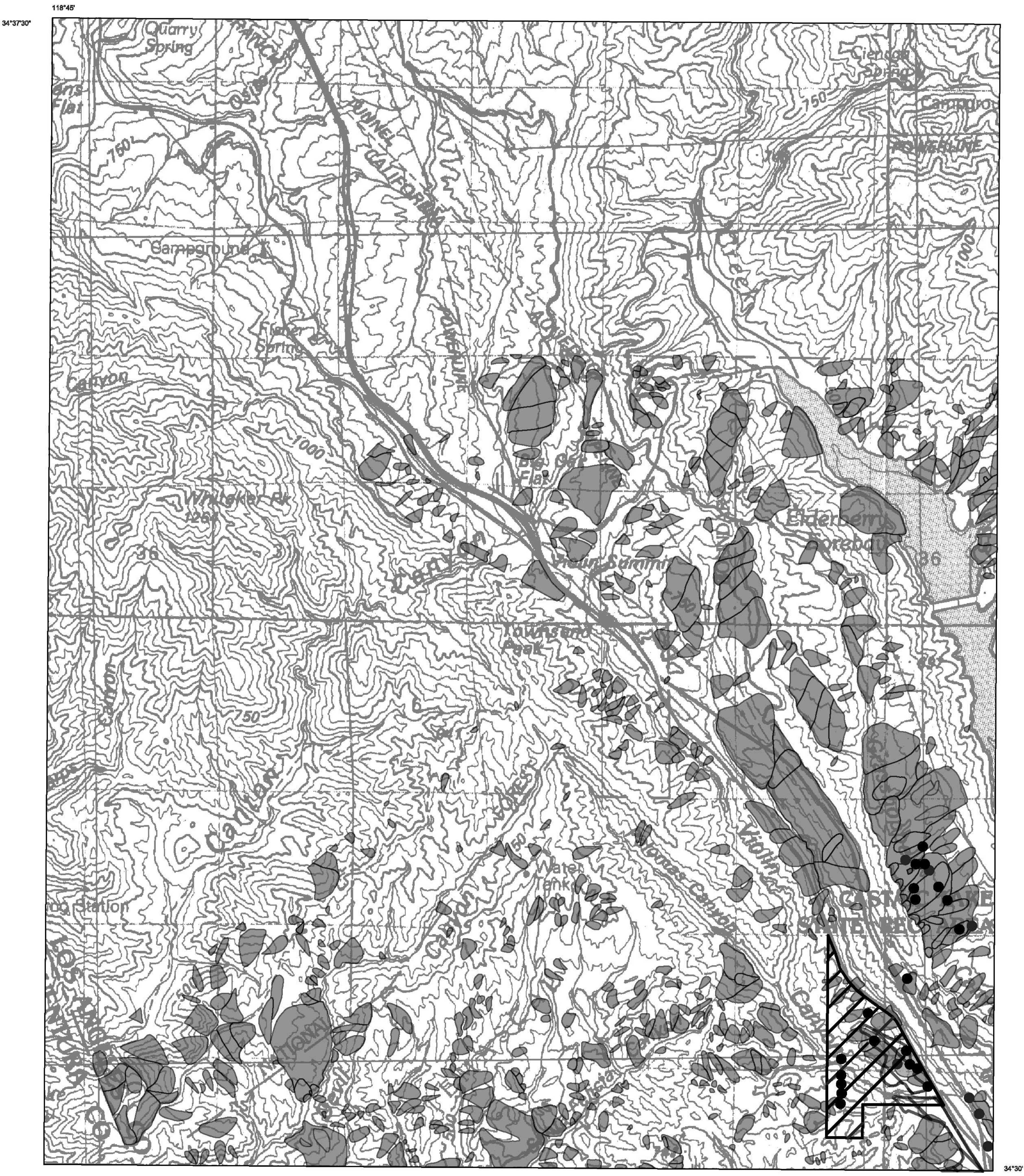
WHITAKER PEAK QUADRANGLE





Depth to ground water, in feet

Plate 1.2 Depth to shallowest ground water, Whitaker Peak 7.5-Minute Quadrangle, California



Base map enlarged from U.S.G.S. 30 x 60-minute series

WHITAKER PEAK QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

● Shear test sample location

Landslide

Area of significant grading

Tract report with multiple shear tests

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Whitaker Peak 7.5-Minute Quadrangle, California.